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# Colour gamut enhancement with remote light conversion mechanism

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## Abstract

The backlight unit spectrum of liquid crystal displays (LCD) directly affects the colour gamut. With the invention of GaN based blue light emitting diodes (LED), phosphors and quantum dots (QD) have gained considerable scientific interest due to their broad range of applications especially in lighting and display technologies. These phosphors and QDs are used to convert the blue light of the LEDs into white in general lighting. On the other hand, in display systems, they are used to generate red and green bands. There are different application methods such as on-chip and remote configurations. In this study, we concentrate on remote phosphor and QD backlight configurations where the light conversion is done away from the chips. In our display designs, we used GaN based blue LED lateral chips as an excitation source, on the other hand, light conversion layers were placed in backlight units as a thin film for the emission of green and red bands. The mixing ratios of these composite layers were arranged to match the emission spectrum of the blue LEDs and the light conversion layer to the colour filters of the LCD, so that the green, blue, and red bands efficiently widens the colour space. The results were also compared with the on-chip phosphor arrangements.

## 1. Introduction

Lighting systems based on blue GaN LEDs require a light conversion mechanism in order to produce other colours. This is generally done at the packaging level by covering the LED die with a colour converting layer which is usually a phosphor containing encapsulant. The composition of this encapsulant is critical in determining the spectral and structural quality of the LED chip [1, 2, 3, 4]. In the early LED applications, these on-chip phosphor conversions became quickly popular and are still widely used in general lighting. However, it was later revealed that placing this conversion layer to a remote position away from the LED die improves the device reliability and lifetime [2, 3, 4]. Analogous approaches are also being used in the implementation of quantum dot containing films into the backlight units for widening the colour gamut of the LCD TVs [5, 6, 7].

Colour gamut is one of the quality parameters of display industry which defines the colour space generated by the display unit. Since the LCD based LED displays can be technically described as the combination of the backlight unit (BLU) and the liquid crystal panel (LCP), the optical design

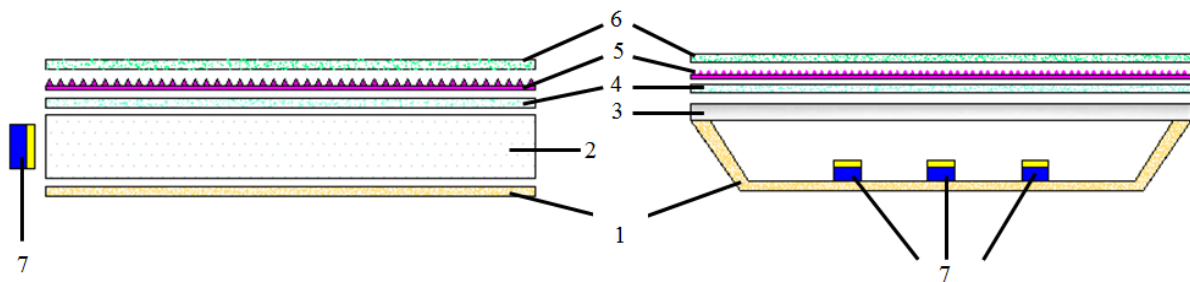


characteristics of both these parts should be compatible to get higher performance from the display system [6].

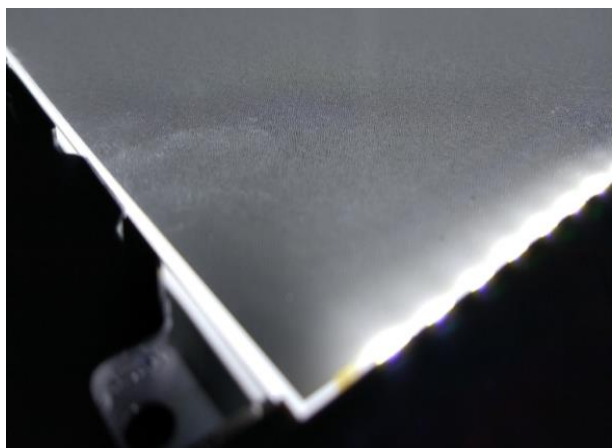
In LED based LCDs, the liquid crystal cells (LC) is illuminated by a backlight unit (BLU). These BLUs are designed as either Direct Light Emitting Diode (D-LED) or Edge Light Emitting Diode (E-LED) configurations according to the position of the LEDs in the BLU. BLUs also include several critical optical components like prism sheets, polarizer sheets, and additional diffuser sheets to improve the homogeneity and brightness (Figure 1).

E-LED designs can be very thin and curved, but their thermal management is difficult due to fact that the light source is located in a narrowly defined area. To solve this issue, the light source is positioned on high cost metallic compounds. Another issue is the distribution of the LED output throughout the BLU. This is done by using a light guide plate (LGP) in which the LED output is propagated by total internal reflection (TIR) (Figure 2).

In D-LED designs, an LGP is not necessary since the LEDs are already positioned in the reflector panel homogeneously and directly. However, this arrangement leads to thicker BLU designs. In addition, the LEDs used in D-LED configurations have a light scattering limit. For this reason, there exists a possibility in case the light output does not smoothly distributed, so the individual LEDs may become visible from the front side of the panel. This problem is generally solved by introducing diffusive elements to the BLU (Figure 3).



**Figure 1.** BLU structure of E-LED and D-LED systems. <sup>1</sup>Reflector sheet, <sup>2</sup>Light Guide Plate, <sup>3</sup>Diffuser Plate, <sup>4</sup>Diffuser Sheet, <sup>5</sup>Brightness Enhancement Film, <sup>6</sup>Reflective Polarizer Film, <sup>7</sup>White LED (Blue chip with yellow phosphor)



**Figure 2.** Light guide plate



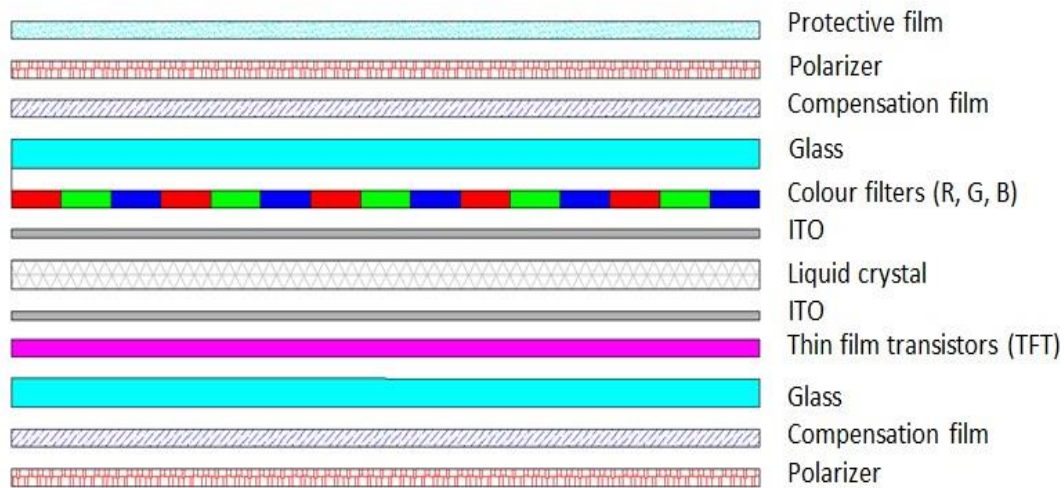
**Figure 3.** Diffuser plate

## 2. Wide Colour Gamut solutions based on phosphor sheets

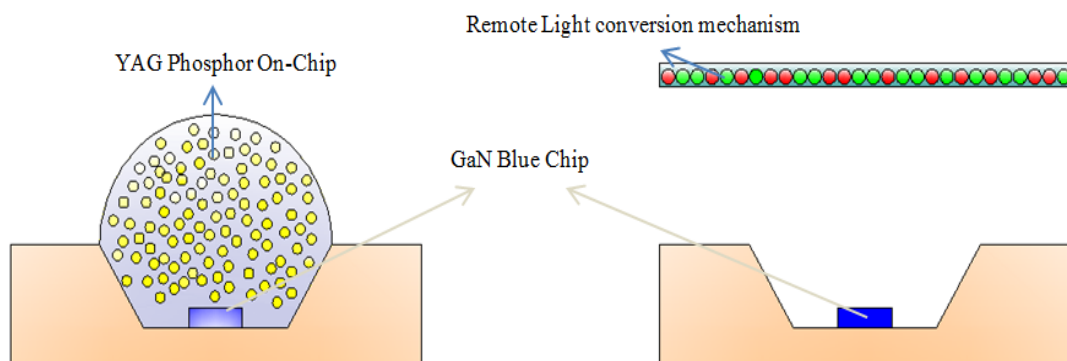
The display quality is generally defined by central luminance, colour coordinates (CIE-x & CIE-y), gamut, and the brightness uniformity. These parameters depend on both BLU and LCD characteristics.

BLU design is critical in brightness and gamut. The optical components of the BLU are generally selected to maximize the light output of the LEDs for the LC panel, while the spectral output should match the LC panel characteristics. Typical LC panel structure depicted in Figure 4 includes blue, green and red colour filters. The combination of BLU spectrum and CF determines the display output gamut and brightness. For this reason, the colour conversion layer and colour filters inside the LC panel should be optically and spectrally compatible. In phosphor based solutions, this is practically done by determining the phosphor blend according to the CF.

To convert the blue light of the LEDs to CF compatible green and red colour bands effectively, narrow band emitting colour converters provide better solutions, since the combined RGB output of the BLU passes through the CF optimally. However, in most displays, single YAG phosphor is used, which results in narrowing of the gamut and loss of brightness. In addition, on-chip light conversions results in extra heat and light loss due to the phosphor containing polymeric encapsulant on top of the LED die [2, 3]. These issues can be solved by locating the phosphor to a remote position (Figure 5) [1, 2, 3].



**Figure 4.** Liquid crystal cell structure



**Figure 5.** LED on chip vs remote light conversion mechanism

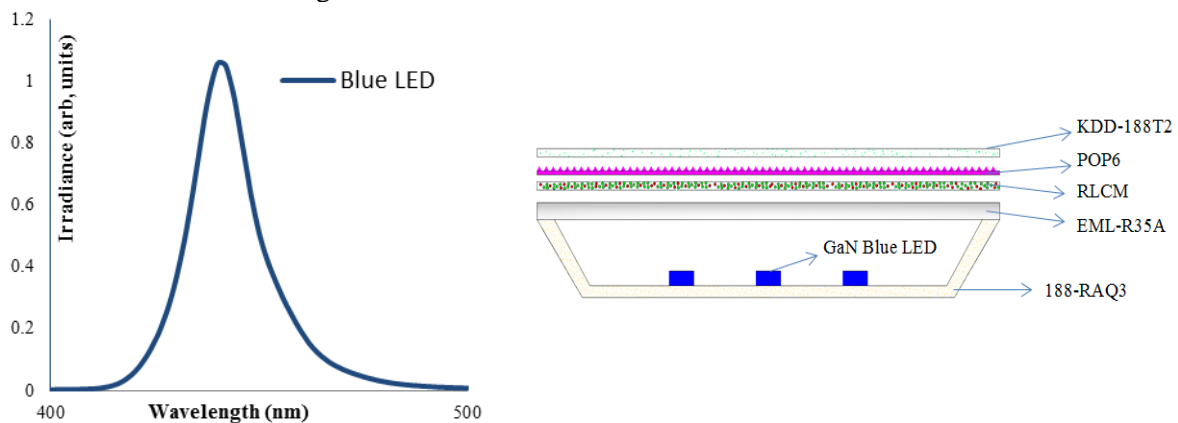
### 3. Phosphor Blending and BLU Design

We have used green and red emitting phosphors in producing colour conversion layers. In addition, we have compared the performance of these layers with commercially available phosphor and quantum dot containing sheets.

The BLU structure used in the experiments contains lateral blue LED chips which have peak emission wavelengths of 444 nm and FWHMs of 19 nm (Figure 6). The optical layers of this BLU design consists of a diffuser plate (EML-R35A), a light conversion layer (RLCM), a prism on prism sheet (POP 6), and an upper diffuser sheet (KDD-188T2). The optical properties of these layers are given in Table 1. These components play significant role on directing the blue light towards the light conversion layer.

The light conversion layer can be placed as a thin-film coating on the diffuser plate or as a roll-to-roll (R2R) film. The advantage of coating the diffuser plate is to prevent the light loss due to barrier films. However, R2R films are preferred for mass manufacturing.

To prepare phosphor containing encapsulants, we preferred optical silicones (Dow Corning OE-7620) and LED phosphors (Mitsubishi Chemical,  $\text{CaAlSiN}_3\text{:Eu}$  and  $(\text{Si,Al})_3(\text{O,N})_4\text{:Eu}$ ). The composite mixture was poured down on a diffuser plate and flattened by Dr. Blade applicator. Then, the coated plate was heat cured at 80°C for two hours. The emission properties these phosphor blends under the excitation of a blue LED are given in Table 2.



**Figure 6.** BLU structure of remote light conversion mechanism

**Table 1.** Optical properties of light conversion mechanism BLU structure

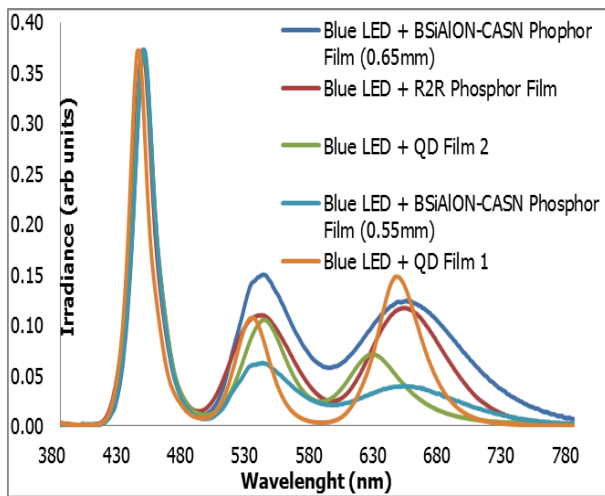
Product Type	Product Code	Thickness (mm)	Reflectivity 555nm (%)	Haze (%)	Transmittance (%)	Used Side Gloss (%)
SMART*	POP6	0.33	N/A	99	3.00	N/A
DP	EML-R35A	1.5	N/A	99	33.00	N/A
RFL	188-RAQ3	0.188	97	N/A	N/A	20.00
UDS	KDD-188T2	0.215	N/A	85	95	N/A

**Table 2.** The properties of  $\beta$ -SiAlON & CASN phosphors

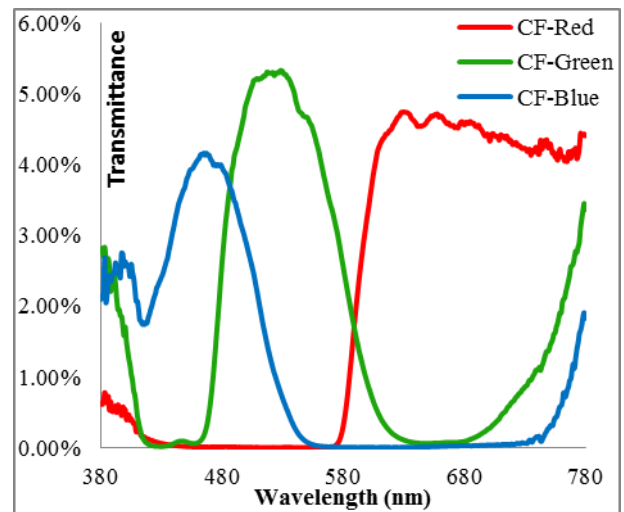
Chemical Formula	Peak Wavelength (nm)	FWHM (nm)	d50 ( $\mu\text{m}$ )
$\text{CaAlSiN}_3\text{:Eu}$	659	88	16
$(\text{Si,Al})_3(\text{O,N})_4\text{:Eu}$	540	52	23.3

#### 4. Experiments and Results

In our display design, we used the BLU structure described above and an LC panel by AUO (65" UHD T650QVN06) which has a transmittance value of % 4.84. The colour conversion is done by phosphors coatings (0.65mm  $\beta$ -SiAlON & CASN & 0.55mm  $\beta$ -SiAlON & CASN), phosphor R2R sheets, quantum dot R2R sheets, and phosphor converted LEDs (pcLED) for comparison (Figure 7). These are designed to match the CF of the LC panel to improve the brightness and gamut. Our panel CF spectrum is given in Figure 8. Here, all these layers were illuminated by the same optical configuration, except the pcLED reference which is measured without the light conversion layer but by using pcLEDs and BLU with the same optical structure.



**Figure 7.** The BLU spectral measurements of  $\beta$ -SiAlON & CASN phosphor blend for different thicknesses (0.55mm & 0.65mm), R2R film, and QD films with respect to white LED



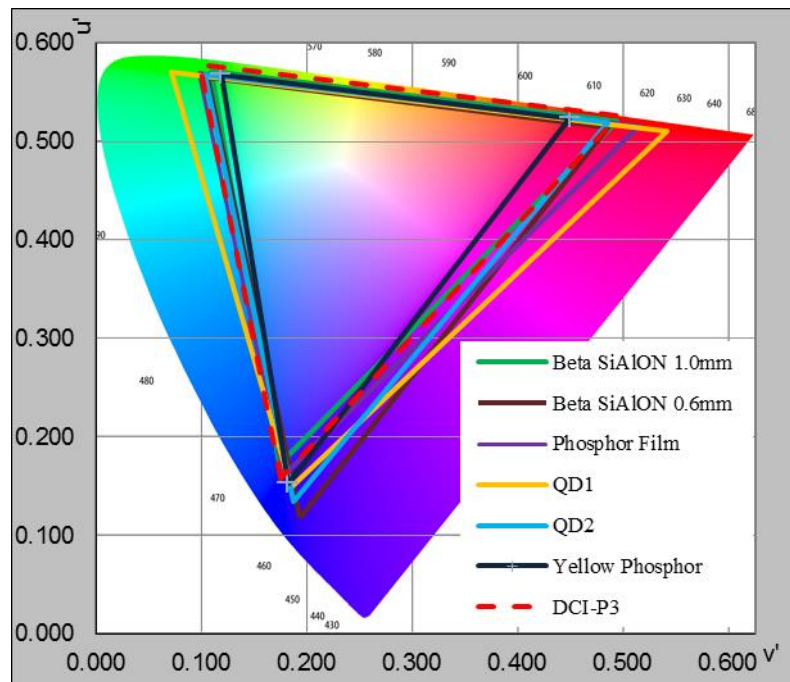
**Figure 8.** CF spectrum of 65" AUO UHD LCC

The colour coordinates and gamut values were measured by using a spectroradiometer (Topcon, SR-3A) at 50cm away from the center of the display. The measurements were performed after a warm-up period of one hour. The results of DCI-P3 coverage and gamut calculations are presented in Figure 10 and Table 3 below.

**Table 3.** Colour gamut and coordinates values of different light conversion mechanisms

Light Conversion Mechanism	$R(u'; v')$	$G(u'; v')$	$B(u'; v')$	DCI-P3 (Area %)	DCI-P3 (Coverage %)
R2R phosphor film	0.515; 0.516	0.098; 0.569	0.178; 0.160	102	96
Beta SiAlON+CASN layer 0.65mm	0.495; 0.521	0.110; 0.572	0.175; 0.172	100	93
Beta SiAlON+CASN layer 0.55mm	0.487; 0.514	0.105; 0.565	0.193; 0.117	102	91
QD Film 1	0.543; 0.511	0.072; 0.571	0.185; 0.149	118	95
QD Film 2	0.486; 0.519	0.104; 0.568	0.187; 0.134	99	93
On-Chip yellow phosphor	0.450; 0.524	0.119; 0.568	0.182; 0.153	82	82
DCI-P3 Colour Gamut Standard	0.496; 0.526	0.099; 0.578	0.175; 0.158	100	100





**Figure 9.** Colour gamut area of  $\beta$ -SiAlON & CASN phosphor blends for different thicknesses (0.55mm & 0.65mm), R2R film, and QD films with respect to pcLEDs at CIE 1976 colour space

## 5. Conclusion

We have performed several light conversion layer types to improve the colour gamut of LCD based displays. Here we have shown that the remote light conversion mechanism is not only effective in expanding the colour space but also useful in thermal management. In addition, it has a direct effect on the lifetime of the system. When it was arranged to match the CF spectra of the LC panel, it also increase the brightness of the display unit. On the hand, these layers can also be prepared by using QDs. However, for heavy metals free QDs, the gamut and intensity values lower than both the phosphor blends and Cd-based QD films. For this reason, phosphor based light conversion layer is expected to be in use for wide colour gamut solutions.

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